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Minimizing occupational exposure to pesticides: Personnel monitoring

By

JAMES E. DAVIS*

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* Wenatchee Pesticides Research Branch, U.S. Environmental Protection Agency, P.O. Box 219, Wenatchee, WA 98801.

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I. Introduction

This communication is presented with two objectives in mind. The first objective is to provide an introduction to personnel monitoring of occupational exposure to pesticides for those who are not familiar with this field of investigation. The second objective is to stimulate discussion, which will result in the formation of recommendations for research necessary for material improvement of exposure assessment.

My first inclination was to present a review of the literature concerned with assessment of occupational exposure to pesticides, placing emphasis on the materials and methods currently being used for these studies. However, that approach would simply repeat information that is already available (DURHAM and WOLFE 1962, WOLFE 1976). I have, therefore, decided to accomplish my objectives by presenting a rather detailed description of a typical exposure study. This description will cover all phases of the study from initial planning to presentation of results. Known weaknesses in methodology and suggestions for changes in methodology that may improve exposure assessments will be included.

It would be impossible to fabricate a hypothetical exposure study that would illustrate all modifications of techniques necessary for application of current methodology to every exposure situation. I will, therefore, present a description of the exposure situation I know best. That is, exposure assessment for the operator of an airblast sprayer who is applying an insecticide cover spray to an orchard. Most of the operations described in this communication are applicable to almost any occupational exposure study. The investigator would simply have to modify such details as location of exposure pads on the study subject, the information noted during collection of field data, and assumptions about typical protective gear.

Two principles were observed in the development of the methods we currently use at Wenatchee and should be preserved by anyone considering modifications. First, all possible care was taken to ensure that any error was on the side of safety, that is, it would result in overestimation of exposure. Second, no technique was considered acceptable if it would increase a test subject's exposure above what he would receive under normal working conditions.

II. Preparation for the field study

I will assume for this hypothetical study that we know well in advance of spraying what chemical is going to be applied and that adequate time is available to perform all of the preliminary investigations that are necessary for a completely successful study. This is often not the case. It is not unusual to be informed, as late as the morning when field work is to begin, that the cooperator, who is supplying the study area, has found an unexpected infestation in his crop. This may result in the

investigator either studying a different spray material or delaying his investigation until the desired material is applied. For this reason, it is to the investigator's advantage to arrange for studies with more cooperators than are actually needed.

a) Selection of methodology

Selection of methodology to be used for any exposure study is determined by the chemical and physical characteristics of the compound being studied and the amount of exposure expected. At this point one must decide which materials and methods are most applicable for collecting pesticide that would impinge on exposed areas of the body and for collecting material that would provide a measure of respiratory exposure. One must also decide what methods are acceptable for extraction of residues from monitoring media and for analysis of extracts.

1. Dermal exposure of areas other than hands.—Two types of dermal exposure pads have been found to be most useful for our studies. For estimation of exposure to liquids a white, blotter-like paper stock approximately one mm thick is used. This is backed with glazed weighing paper to protect the pads from contamination by pesticides already on the worker's clothes or skin. For dusts, granular materials, dried residues, or in situations requiring greater than normal mechanical strength, a pad constructed from layers of surgical gauze is used. These pads are backed with squares of filter paper to eliminate contamination from the clothes and body. Details of the construction and use of both these types of pads were presented by DURHAM and WOLFE (1962), who referred to the paper stock as alpha-cellulose.

Both of these types of pads have minor drawbacks. If one is assessing exposure to low levels of pesticides and finds that concentration of extracts is necessary for quantitation, both alpha-cellulose and surgical gauze may contain materials that interfere with analysis. These materials will have to be removed by extraction prior to use. Also, the alpha-cellulose stock is difficult to obtain in the relatively small quantities required by most laboratories.

Since we are investigating the application of a spray for our hypothetical study, we would select alpha-cellulose pads.

2. Hand exposure.—The bag rinse technique described by DURHAM and WOLFE (1962) is generally used to remove residues from the hands. The solvent most commonly employed is ethanol, although distilled water has also been used (WOLFE *et al.* 1961). One might also want to consider the use of absorbent gloves to entrap toxicant before it reaches the hands.

DURHAM and WOLFE (1962) did not describe the use of absorbent gloves because they felt that their use might result in exceptionally high estimates of exposure to the hands. The gloves might tend to absorb much more liquid than could be expected to adhere to flesh (WOLFE

1979). This would not be objectionable according to the principle that methods resulting in overestimation of exposure are acceptable. However, in this case excessive overestimation might result in the unnecessary loss of use of important pesticides. The reason for this is that, in nearly all studies of occupational exposure to pesticides, approximately 90% of the dermal exposure is found on the hands. A large overestimation of this component of exposure could result in the loss of registration of vital pesticides with small margins of safety, whereas overestimation of exposure to other areas of the body would have little consequence.

If it is found that absorbent gloves can be used without excessive exaggeration of exposure, they present the investigator with several attractive advantages. Even though the bag rinse technique is faster than removing residues from the hands by swabbing, it is still a relatively slow process. Any process that significantly slows the workers at a commercial operation must be reevaluated to see if better methods can be found. Solvents other than water and ethanol cause loss of skin oil and result in irritation and cracks that will increase a worker's dermal absorption of toxicants. Some compounds are not very soluble in either water or ethanol, so their recovery is not acceptable using these solvents. Water and ethanol may interfere with analyses or cause degradation of extracted residues. Finally, toxicant absorbed into the hands during the exposure period is not included in the exposure estimate. The use of gloves could help alleviate all of these problems.

On the other hand, gloves contain materials that may interfere with analyses. These materials are often hard to remove. It may prove difficult to get workers to wear even thin cotton gloves for certain operations. Also, covering residues already on the hands with gloves may result in increased exposure of the test subjects due to increased penetration because of occlusion (MAIBACH and FELDMAN 1974).

Because of the large contribution of residues on the hands to total exposure, improvement of methodology used for estimation of hand exposure should be a major objective of investigators of pesticide exposure.

3. Respiratory exposure.—Methodology used for estimation of respiratory exposure to pesticides can be subdivided according to whether the monitoring is by the direct method, which utilizes respirator pads, or by measuring concentrations of toxicant in air. Monitoring by measurement of air concentrations can be further subdivided according to whether the sampling system is portable enough to be worn by the test subject or is so large that it is restricted to a fixed location. Portable sampling systems are usually called personal monitors. At the Wenatchee Pesticides Research Branch, we generally use respirator pads or personal monitors to assess occupational exposure, so I will limit this discussion to these two techniques.

Even though the direct method is preferred because of its simplicity, if the pesticide is not trapped by respirator pads, one will have to resort

to measuring the concentration of toxicant in air. Conversely, the personal monitor method might be preferable because of better trapping efficiency; however, levels of toxicant in the air may be so low that the limited flow of these monitors will restrict the amount of toxicant trapped to a level below the sensitivity of the analytical method available. In this situation use of less efficient respirator pads may allow trapping of sufficient toxicant for analysis; however, a correction will have to be made for sampling error. For instance, if the trapping efficiency was 75%, the actual respiratory exposure would be the experimental respiratory exposure divided by 0.75.

The technique currently used for direct determination of respiratory exposure to pesticides is essentially the same as described by DURHAM and WOLFE (1962). Those investigators recommended the use of an alpha-cellulose respirator pad faced with several layers of surgical gauze for trapping dry materials and a plain alpha-cellulose pad for trapping liquids. Respirator pads currently available are not as thick as those originally used by DURHAM and WOLFE, so we now employ the gauze-faced pads for all studies.

I want to reiterate that a worker is never subjected to greater than normal exposure. If the worker is not wearing respiratory protection or is only using a dust respirator, he may be asked to wear a modified dust respirator fitted with the gauze-faced pads. However, if he is wearing a canister type respirator, he must be provided with a similar type respirator modified to hold exposure pads in front of the canisters.

The most important advantage of the direct method, in contrast to use of personal monitors, is that the subject supplies the airflow and all toxicant that would be drawn into the nares during the exposure period is trapped. This eliminates the need for the investigator to make an estimate of minute ventilation for the subject. To determine the potential hourly exposure, one only needs to multiply the amount of material found on the pad, or both pads, if a double canister respirator was used, by a factor which is determined by the length of the exposure period. Modification of the respirator to eliminate direct drift and fabrication of the gauze-faced pads are relatively simple operations. Another advantage is that the procedure used for extraction of toxicant from dermal exposure pads is applicable to respirator pads.

The major disadvantage of monitoring respiratory exposure by the direct method is, of course, that the gauze-faced exposure pads may not be an efficient trapping medium for the material being studied. When used with dust respirators, the exposure pads often become very wet due to exhaled moisture. This may lead to hydrolysis of sensitive compounds. Finally, it sometimes is very difficult to convince a worker to wear a respirator, if he does not normally wear one, for the operation being studied. In these cases, we often are able to reach a compromise so that the worker will wear a respirator for one out of every two exposure periods.

In some situations where respiratory exposure to pesticides could not be determined by use of respirator pads, personal monitors have proven effective. These monitors consist of a small, battery operated pump connected to a collection device, which is positioned as near as possible to the worker's breathing zone. LINCH (1974) presented a fairly complete description of this technology; however, he did not include specific information about monitoring pesticides. VAN DYK and VISWESWARIAH (1975) and LEWIS (1976) reviewed sampling for airborne pesticides; however, their reviews do not stress the use of personal monitors. Taken together, these three aforementioned references are a good starting point for anyone new to this area of investigation.

Investigations of respiratory exposure to pesticides using personal monitors have generally utilized midget impingers filled with ethylene glycol or other liquids to trap the toxicant. Even though ethylene glycol is a very good trapping agent for a large number of pesticides, this technique has a number of disadvantages. Ethylene glycol also traps water from the air, which may lead to hydrolysis of sensitive compounds. Liquids are easily spilled from the midget impingers during many work activities. Commercially available ethylene glycol contains materials that may interfere with analysis, and which must be removed by extraction before the ethylene glycol is used (THOMPSON 1977). Finally, one must devise an extraction procedure that will efficiently partition the pesticide from the ethylene glycol into a solvent that is suitable for the applicable analytical procedure.

A relatively new technology is evolving, which allows the use of solid absorbents with personal monitors. Absorbents which have actually been used in personal monitors for field studies of occupational exposure to pesticides include GC Durapak-Carbowax 400/Porasil F (MELCHER *et al.* 1978) and Chromosorb 102 combined with polyurethane foam (HILL and ARNOLD 1979). Membrane filters have also proven effective for trapping a number of pesticides (SPEAR *et al.* 1977, HILL and ARNOLD 1979).

It is fortunate that respiratory exposure is generally a very small component of the total exposure received during use of pesticides. Improvement of methodology to measure respiratory exposure may well prove to be the most difficult task facing investigators of occupational exposure to pesticides.

Three areas of research could significantly improve methodology for assessment of respiratory exposure to pesticides using personal monitors. The first is further investigations to establish a battery of efficient solid absorbents that will cover the entire spectrum of pesticides. Second is modification of absorbent containers or the physical state of the absorbents to increase airflow when using portable pumps. Finally, systems should be investigated that will allow direct, undiluted transfer of total sample from the absorbent directly into an appropriate analytical instrument.

4. Selection of extraction and analytical methodologies.—The methodologies to be used for extraction of residues from exposure pads or

personal monitor media and for analysis of extracts will be determined by the nature of the chemical under investigation and the levels of exposure expected. It is, therefore, impossible to give specific guidance for their selection. We have found that satisfactory recoveries of residues from exposure pads may be obtained either by Soxhlet extraction or by simply shaking the pads in solvent. Gas chromatography has been our usual choice for analysis because of sensitivity.

In the past we generally used benzene for Soxhlet extractions. Since the advent of strict safety requirements for the use of benzene, we have had good results using an azeotropic mixture of 59% acetone and 41% hexane. This mixture boils at approximately 50°C, which is convenient for soxhlet extractions, and is a good solvent for both polar and nonpolar pesticides. The only disadvantage we have found is that acetone may cause difficulties with some analytical procedures. If exposed pads are extracted by shaking with a solvent, then the choice of solvents is only limited by their compatability with the analytical procedure and the ease with which extracts can be concentrated.

It is difficult to estimate what sensitivity will be required for analysis. Studies of materials with greatest toxicity and studies of occupations with lowest potential for exposure require the most sensitive procedures. As a rule of thumb, the analytical procedure should be capable of quantitative detection of one $\mu g/cm^2$ of residue on the exposure pads.

b) Validation of methodology

Unfortunately, it is often difficult to determine whether or not some investigators validate their methodology properly. They either ignore this aspect of the investigation or simply fail to document it in their communications. Without assurance of proper validation, their methodology and estimates of exposure must be viewed with skepticism.

For our hypothetical study, several possible sources of experimental error will be investigated. The collection efficiency of the respiratory exposure monitoring system must be determined. The extraction efficiency of the methods that will be used for extracting residues from dermal exposure pads and the respiratory exposure monitoring medium must also be determined. In addition, if exposed dermal pads or respiratory exposure monitoring media are to be stored pending extraction, the storage stability of residues on these materials will have to be determined. If extracts will be stored pending analysis, the stability of the pesticide will have to be determined in the solvents used for extraction of exposed dermal pads and respiratory exposure monitoring media. Finally, the stability of the pesticide must also be determined in the solvent that will be used for hand rinses.

1. Collection efficiency of respiratory monitoring media.—Apparatus, such as that designed by MELCHER *et al.* (1978), have been developed

to determine the efficiency with which solid absorbents collect pesticides in the vapor state. DURHAM and WOLFE (1962) used a similar principal to determine the efficiency with which respirator pads collected parathion from water solutions or parathion dust. Unfortunately, a standard procedure has not been developed to measure the efficiency with which either of these media trap aerosols. Until a standard procedure is developed, each investigator will have to devise his own method for determining collection efficiency.

2. Determination of extraction efficiency and of the stability of stored extracts.—One must also determine the efficiency of the procedure chosen to extract residues from dermal exposure pads and respiratory monitoring media. In addition, if extracts are to be stored pending analysis, the stability of the pesticide in the extracts must be determined.

For our hypothetical exposure study, we would determine the extraction efficiency and storage stability as follows. We have found that a mean dermal residue of approximately ten $\mu g/cm^2/hr$ will result if a sprayman is applying a spray containing 681g (1.5 lbs) of active ingredient/0.405 ha (1 A) in 1,516 L (400 gal) of water by airblast sprayer. From this we are able to estimate the residue that can be expected with other sprays. For instance, 1.36 kg (3 lb) of active ingredient applied/0.405 ha in 1,516 L (400 gal) of water should result in a mean dermal exposure of 20 $\mu g/cm^2/hr$. Since we normally monitor a sprayman for approximately 30 min between pad changes, we would fortify pads with 10 $\mu g/cm^2$ to study the extraction efficiency and storage stability of the material to be applied at this second rate. If a study involves other operations or spraying methods, one should fortify at several concentrations for the first experiment to make sure one is in the correct concentration range. We also know that the first spray situation mentioned above will result in a mean respiratory exposure of approximately 0.2 mg/hr. From this we can determine the fortifying level that should be used for respiratory media.

We would fortify the materials to be used for dermal exposure pads and respiratory monitoring media with the appropriate amount of pesticide, extract the residues, and determine recoveries. The solution used for fortifying should be prepared from authentic spray material diluted to the same concentration as will be used for the field study. Authentic spray material is used to compensate for effects of spray adjuvants on extraction efficiency, which would not be included if one used analytical standards for these studies.

Since we normally store extracts for some time before analysis, we must also determine the stability of the pesticide in the various solvents used for extraction The simulated extracts prepared above to determine extraction efficiency are also used to determine stability. In addition, we must prepare fortified samples that simulate hand rinses, unless the simulated exposure pad or respiratory monitoring media extracts were prepared using the same solvent as will be used for hand rinses A typical

concentration for pesticides found in the hand rinses from airblast applicators is one mg/200 ml, so we would prepare simulated hand rinses containing that concentration of authentic spray concentrate. These simulated hand rinses would also be analyzed prior to storage.

The simulated extracts and hand rinses would be re-analyzed after at least two periods of storage under the conditions to be used for storing authentic samples. The periods of storage would be chosen so that the longest corresponds to the longest projected storage period for authentic samples and so that a decay curve could be constructed. This would allow correction for loss of residues from authentic samples.

3. Determination of the stability of residues on stored sampling media.—Later, when the processing of exposed sampling media is discussed, two options will be offered. One of these options involves storing exposed media until the investigator has time to extract them. If one chooses that option, then he will have to determine the stability of the pesticide on the media during storage.

For our hypothetical exposure study, we would prepare additional simulated exposed dermal pads and respiratory media in the same manner as was used for determining extraction efficiency. These additional fortified pads and media would be stored in the same manner as would be used for storage of actual field samples prior to extraction. After at least two periods of storage these fortified pads and media would be extracted and the extracts analyzed. The periods of storage would be chosen so that the longest corresponds to the longest projected storage period for authentic field samples and so that a decay curve could be constructed. This would allow correction for loss of residues during storage of exposed media.

4. Determination of losses from exposure media during the exposure period.—For most pesticide exposure studies, losses of residues from exposure media due to volatilization or decomposition during the exposure period has been assumed to be insignificant. If the pesticide is particularly volatile or sensitive to hydrolysis or oxidation, one may have to take these losses into account. Losses from respiratory media would be detected in the study to determine the collection efficiency of the media. A separate study would be necessary to detect losses from dermal exposure pads.

Maitlen and Sell (1979) at the U.S. Department of Agriculture Laboratory in Yakima, Washington, have attempted to take these losses into account for their studies of applicator exposure to carbaryl. They fortified dermal exposure pads at approximately the levels expected for field samples and wore the pads outside for various periods of time. The loss was found to be up to 15% of the applied material. Unfortunately, the loss could not be correlated to the time the pads were worn. Changing outside temperature and humidity as well as variable exposure of the pads to sunlight may have been major factors responsible for their irregular losses.

Research is needed to establish a suitable procedure for evaluation of these losses.

c) Dermal exposure pad location

One must decide in advance where to locate the dermal exposure pads on the study subjects. Because of the added cost of analyzing superfluous pad extracts and the effect changing unneeded pads would have on slowing workers, one should carefully consider the necessity for any proposed location. Pads should generally be placed only in locations necessary for the determination of exposure to normally exposed skin.

For assessment of exposure of our hypothetical airblast applicators, we would assume that they normally wear short-sleeved shirts and long trousers. Pads would be located at the shoulders, upper back, and upper chest to find the exposure to face and neck. Pads would also be attached to the forearms to find the exposure in those areas. For convenience, clothing over the rest of the body would be assumed to be impenetrable, even though this leads to a slight underestimation of exposure. As an example for other exposure situations, if it is typical for the workers to wear shorts instead of long trousers, then one would also include pads on the thighs and ankles to allow evaluation of exposure to the upper and lower legs. Other pad locations are mentioned by DURHAM and WOLFE (1962); however, we generally do not use those locations for normal exposure assessment.

In addition to the use of pads over clothing and on areas of exposed skin to assess exposure to unprotected areas, pads may also be placed under clothing or protective gear to determine the degree of protection afforded by various garments. This technique also allows one to correct for exposure due to penetration of clothing that is not really impenetrable.

d) Selection of study subjects

It would be ideal if each investigator of occupational exposure to pesticides could locate workers who only received typical exposures. Since this type of worker is hard to find, the investigator can only do his best to ensure that his overall results are typical. Rather than obtaining all exposures for a study from one operation, one should obtain a small number of exposures from several workers at different places of employment. This approach helps to prevent one from assessing exposures using only workers who are well trained and exceptionally careful or only workers with no appreciation for safety. It does not require much experience before an investigator is readily able to judge a worker's attitude and thereby his potential for exposure.

On the other hand, if the investigator is comparing the effect of various application variables on exposure or is comparing one method for exposure assessment to another, then many exposures utilizing a small number of workers may give better results. Most experienced workers

have a relatively rigid and individual way of performing their duties. This tends to result in relatively uniform exposures from day to day.

e) Briefing study subjects

Another important part of any exposure study is a briefing of the study subjects prior to the collection of field samples. This briefing serves two purposes. First, it allows the study subjects to give truly informed consent for their participation in the study. Second, it helps to insure that the results one obtains are typical of normal working exposures.

Unless one explains the study to the workers and informs them that they are under no obligation to participate, their supervisor will often just tell them to cooperate with no questions asked. Even though the investigator is not endangering the worker through monitoring, the worker still has a right not to participate. If some workers initially decline to participate, they will often volunteer their services after seeing that their participating coworkers are not being unduly inconvenienced. This is particularly true for workers who decline to wear a respirator in dusty conditions.

If one begins to monitor workers without explaining the purpose of the study, the workers often get the idea that the material being studied is unusually dangerous. This causes them to be extra careful, so the results obtained are not truly typical.

III. Field operations

The major objective of this section is to provide the prospective investigator of occupational exposure to pesticides with suggestions that will make his first field study a little easier.

a) Selection of operational site

The ideal site from which to study an operation is close to a natural stopping site for the workers, gives the investigator a clear view of the study subjects during their exposure period, and is out of the way of normal traffic and pesticide drift. It is usually impossible to find this ideal site.

For our studies of exposure during airblast application of pesticides to orchards, we generally work from the tailgate of a station wagon parked between a row of trees near the sprayer fill site. This location is near a natural stopping site, is out of the way of traffic and drift, but is not a good location from which to observe the applicators except when they are filling their rigs. Therefore, we must periodically go to a position between the rows of trees being sprayed, in order to observe the applicators during that phase of exposure.

b) Attachment of dermal exposure pads

Dermal exposure pads may be attached directly to the study subject using masking tape; however, this procedure is not recommended if one does not wish to slow the workers at a commercial operation. A special harness can be constructed, which allows changing of the pads at the shoulders, back, and chest in a few seconds. Another good system is provided by taping the pads to a number of light weight, semidisposable spray jackets before beginning the day's study. By substituting a fresh jacket, all of the pads on the upper body can be changed very quickly. This also includes the forearm pads, which must be handled separately, if the harness is used. It is important that the tape used to attach the forearm and ankle pads is of sufficient length to allow complete freedom of movement for the sleeve and cuff.

c) Field data collection

The data that must be collected in the field will vary with the exposure situation being investigated. A data sheet must be compiled for each set of dermal exposure pads, respiratory media, and hand rinses. These data sheets must be indexed so that they can easily be related to any particular exposure value. We feel that it is better to collect data that may later prove to be superfluous rather than to collect too little data. Observations that may not seem too important, when data is being collected, may later help to explain anomalous results. An example of the type of data we collect for a particular exposure situation is given below.

These are the data that would be collected for an agricultural application:

(1) Investigator's name, date of study, and study-identification code number.

(2) The chemical applied, formulation, lot number, and size of concentrate container.

(3) Description of the site—crop, plot size, row spacing, and height of crop.

(4) Tank mix used and application rate.

(5) Spray rig data—type, make, and model of sprayer; nozzle size; pressure; height of nozzle above ground; and speed of application equipment.

(6) Weather data—relative humidity, wind conditions (steady or gusty), wind speed, wind direction, sun condition (clear, partially cloudy, or overcast), and temperature.

(7) Duties of the study subject during the exposure.

(8) Location of exposure pads on the subject and sample numbers corresponding to these pads.

(9) Exposure observations—direction of applicator's travel or tank filler's position in relation to wind direction, clothing normally worn by the study subject, and any special circumstances observed that might

alter normal exposure such as splashing concentrate directly on a particular pad while filling sprayer.

(10) Exposure time—separate times are noted for different operations such as filling sprayer and spraying. For hand rinses, the total time since the last hand rinse or since beginning work is needed.

d) Duration of exposure

It is impossible to specify a particular duration of exposure that will give satisfactory results for a particular operation. The exposure period must be long enough to collect measurable residues, if exposure is occurring, but short enough to avoid excessive losses due to volatilization or decomposition. Studies at our laboratory gave the following results, which may serve as a guide:

Airblast orchard spraying—measurable residues on most pads after 30 to 60 min.

Tractor drawn low-pressure boom sprayers—few quantifiable residues on pads after 2 hr.

Back-pack type hand sprayers—measurable residues on most pads after 3 to 4 hr.

Formulating plant workers—measurable residue on mixer's, bagger's, and stacker's pads after 30 to 60 min.

Spraying yards or gardens with hand pressure sprayers or garden hose sprayers—measurable residues on most pads after 15 min.

e) Processing exposed monitoring media

Exposed dermal pads may be processed using two procedures. These procedures, with minor modification, are also applicable to exposed respirator pads. The first procedure involves placing a portion of an exposed dermal pad or an entire exposed respiratory pad immediately into the solvent which will be used for extraction. A template of convenient size is placed behind a dermal pad and the outside, including the area which may have been covered by the tape used to fasten the pad to the subject, is trimmed away. After the protective backing is discarded, the trimmed portion of exposed pad is placed in a prelabeled bottle containing solvent and drying agent.

The second procedure involves storage of the exposed dermal pad, with protective backing removed, or the exposed respiratory pad in a labeled protective envelope constructed from filter paper (Durham and Wolfe 1962). The pad inside of the envelope is placed in an unwaxed-paper sandwich bag for storage. After returning to the laboratory, the protective envelope and pad are removed from the bag and a portion of the exposed dermal pad and the protective envelope in contact with it are cut out for extraction. It is necessary to include the portions of protective envelope, as they may have absorbed pesticide from the exposed

pad. If the protective envelope contains an exposed respirator pad, the envelope is trimmed around the circumference of the pad.

Each of these procedures has a disadvantage. The first procedure decreases the time available for the investigator to observe the work habits of the study subjects and may require extra personnel in the field to handle the workload. The second procedure generates the need for a study of the storage stability of the compound under investigation, since significant degradation or volatilization may occur between the time the exposed pads are removed from the worker and the time when the pads are extracted.

It should also be possible to process exposed solid absorbents from personal samplers in the field or at the laboratory. Ethylene glycol, however, cannot be conveniently extracted in the field.

f) Hand exposures

If absorbent gloves are used for hand exposure, they can be changed at the same time as exposure pads. Rinsing hands, however, is too slow to be used very often when studying commercial operations. We generally only rinse the hands when workers are taking breaks. This usually limits us to 4 rinses/day/worker. These are performed at mid-morning, before lunch, mid-afternoon, and at quitting time.

IV. Exposure assessment

In order to compare data between exposure studies, it is necessary to follow a standard protocol for calculation of dermal exposures. Also, it is impossible to evaluate the effects of the numerous variables that may alter exposure, unless one is careful to specify all of the operational parameters noted during the field studies. I would, therefore, suggest that the following procedures be followed for calculation of exposure and presentation of final results.

a) Calculation of dermal exposure

The following example for calculation of dermal exposure is simply a detailed description of the procedure suggested by DURHAM and WOLFE (1962).

The residue/unit area of exposure pad surface is multiplied by a time factor, which is determined by the length of time the worker is exposed, to derive the hourly exposure per unit area. One must then choose which pads shall be used to represent the various unprotected regions of the worker's body. A suggested pairing of exposure pad locations and body regions is shown in Table I. The hourly exposure/unit area of a pad, or the mean hourly exposure/unit area if two or more pads represent a body region, is then multiplied by the surface area of the unprotected

Table I. *Dermal exposure pad locations used for calculation of exposure of unprotected regions of the body and surface areas of those regions.*

Body region	Exposure pads used to represent body regions	Surface area of region (cm^2)[a]
Face	Shoulder pads	650
Back of neck	Back pad	110
Front of neck	Chest pad	150
Back	Back pad	3,550
Chest and stomach	Chest pad	3,550
Upper arms	Shoulder pads and forearm pads	1,320
Forearms	Forearm pads	1,210
Hands	Total residue in hand rinses or on absorbent gloves are used without regard for surface area	820[b]
Thighs	Thigh pads	2,250
Lower legs	Ankle pads	2,380

[a] Calculated from data of BERKOW (1931), DIEM and LENTNER (1970), and DURHAM and WOLFE (1962).

[b] Surface area of the hands is only necessary if partial swabbing or pads attached to the hands are used for collection of residues.

body region. Suggested surface areas, representative of an adult male, are also shown in Table I.

The total hourly dermal exposure of the subject is the sum of the hourly exposures for the individual unprotected body regions plus the hourly exposure of the hands. If swabbing or pads are used to determine residues on the hands, then the hourly hand exposure is calculated in the same manner as exposures for the other unprotected regions. If hand exposures are determined by bag rinses or the use of absorbent gloves, the hourly hand exposure is simply the total residue found in the rinse or glove extract multiplied by the time factor.

For example, suppose our hypothetical sprayman was monitored for 30 min and the unit area residues found on his exposure pads were: right shoulder, 2 $\mu g/cm^2$; left shoulder, 1 $\mu g/cm^2$; back, 1.5 $\mu g/cm^2$; chest, 0.5 $\mu g/cm^2$; right forearm, 4 $\mu g/cm^2$; and left forearm, 3 $\mu g/cm^2$. Also, suppose his hand rinses contained 4,000 μg in the right bags and 3,500 μg in the left bags. Since his exposure time was 30 min, his hourly exposure/unit area for the above locations would be twice the above values. Using the pad locations and surface areas suggested in Table I, his hourly exposure for exposed body regions would be:

$$\text{Face} = [(4\ \mu g/cm^2/hr + 2\ \mu g/cm^2/hr) \div 2] \times 650\ cm^2 = 1{,}950\ \mu g/hr$$

$$\text{Back of neck} = 3\ \mu g/cm^2/hr \times 110\ cm^2 = 330\ \mu g/hr$$

$$\text{Front of neck} = 1\ \mu g/cm^2/hr \times 150\ cm^2 = 150\ \mu g/hr$$

$$\text{Forearms} = [(8\ \mu g/cm^2/hr + 6\ \mu g/cm^2/hr) \div 2] \times 1{,}210\ cm^2 = 8{,}470\ \mu g/hr$$

$$\text{Hands} = 8{,}000\ \mu g/hr + 7{,}000\ \mu g/hr = 15{,}000\ \mu g/hr$$

$$\text{Total dermal exposure} = 25{,}900\ \mu g/hr$$

The above calculations assume that the sprayman was wearing a cap, short-sleeved shirt, long trousers, and shoes; and that his clothing was impenetrable to spray.

b) Calculation of respiratory exposure

If respirator pads had been used to monitor our hypothetical sprayman, then one would only need to multiply the total residue found by a factor determined by the length of time the sprayman was exposed. For example, if 0.03 μg was collected during the 30 min exposure, the respiratory exposure would simply be 0.06 μg/hr.

If a personal monitor had been used, one would have to make an estimate of the sprayman's minute ventilation to calculate his hourly exposure. Rough estimates for minute ventilation under various work conditions are available (DURHAM and WOLFE 1962, DIEM and LENTNER 1970). Minute ventilation has also been estimated for a study of occupational exposure to pesticides using a calibrated pulse rated method (SPEAR *et al.* 1977).

For example, if our sprayman's monitor had collected 0.003 μg of pesticide during the 30 min exposure, the personal sampler had a flow of 2 L/min, and we estimate the sprayman's ventilation to have been 20 L/min, then the hourly respiratory exposure can be calculated as follows:

$$\text{Volume of air sampled} = 2\ L/min \times 30\ min = 60\ L$$
$$\text{Pesticide concentration in air} = 3 \times 10^{-3}\ \mu g \div 60\ L = 5 \times 10^{-5}\ \mu g/L$$
$$\text{Hourly ventilation of sprayman} = 20\ L/min \times 60\ min/hr = 1{,}200\ L/hr$$
$$\text{Hourly respiratory exposure} = 5 \times 10^{-5}\ \mu g/L \times 1{,}200\ L/hr = 0.06\ \mu g/hr$$

c) Presentation of results

In the past, I have attempted to use published exposure data to correlate exposure with variables such as concentration of spray used in airblast applications. Such correlations will be necessary for prediction of exposure without actual field studies. Unfortunately, most communications seem to lack at least one piece of vital information. For instance, spray concentration alone is not enough information. One must also know

what the rate of application was. I believe it would be much more desirable for authors of communications concerning occupational exposure to include too much data about variables that may effect exposure rather than too little data. I cannot specify exactly what this data should be, since it will vary with the occupation studied and may include variables that we do not expect will alter exposure.

One specific suggestion I have is that dermal exposure be reported for individual areas of the body. The exposure of applicators who also fill their own spray rigs provides an example of a study situation in which total dermal exposure is insufficient information. Their hand exposure is not a function of the concentration of spray applied, so one cannot predict their exposure from previous studies carried out using different spray dilutions, if only total exposure is reported. Also, if a pesticide is found to lack a sufficient margin for safe use based on the protection assumed for a safety evaluation, then knowing the exposure to various areas of the body, one may be able to specify that use is safe, if particular items of protective gear are worn.

Summary

Methodology most commonly used for monitoring occupational exposure to pesticides is presented with two objectives in mind. The first objective is to furnish a primer on personnel monitoring for those who are new to this field of investigation. The second is to stimulate the formation of recommendations for further research that will materially improve exposure assessment.

A hypothetical pesticide exposure study is followed from selection of appropriate methodology through presentation of results. Airblast application of an orchard cover spray was chosen as the example of a typical study. Emphasis is placed on selection of methodology, validation of methodology, field operations, and standardization of calculations.

The advantages and disadvantages of the various methods available for monitoring both dermal and respiratory exposure are discussed. Suggestions based on the author's personal experience are included. These are intended to facilitate the initial exposure study by investigators who have not had experience with this type of research.

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